Durability and Damage Tolerance Enhancements Using *FTI* Processes

D.J.Reddy

Technical Consultant

to FTI

DER Conference

May 25, 2006

Outline

- Objectives
- Airplane vs. Helicopter
- Key Design Parameters for Rotor Systems
- Durability vs. Damage Tolerance
- Helicopter Certification Process
- Safe Life Methodology
- Damage Tolerance Methodology
  - Damage Tolerance- Metallic Components
  - Damage Tolerance-Composite Components
- *FTI* Products & Processes
- Advantages of ***FTI*** Products & Processes for:
  - Fatigue improvements
  - Damage tolerance improvements
- Applications of ***FTI*** in Rotorcraft Industry
- *FTI*- Composites Research
- Conclusions

Objectives

- Differences in airplane and helicopter durability and damage tolerance characteristics
- Provide brief background in structural design and certification process of helicopter components
- Durability vs. Damage Tolerance
- How FTI processes can enhance durability and damage tolerance of structural components
- Description of FTI Processes and Products

Airplane vs. Helicopter

- Fatigue Loading
  - Airplane - Occurs at takeoff and landing with few smaller loading cycles in flight
  - Helicopter - Occurs during every rotor revolution in rotors and some areas of airframe structure

- Fatigue Cycles
  - Airplane - Typical number of fatigue cycles in a lifetime are usually less than a million cycles in life time
  - Helicopter - Can accumulate million cycles cycles in less than 50 hours

- Crack Growth
  - Airplane - Slow and gradual in the structure and inspections are practical before crack reaches critical length
  - Helicopter - Slow in the beginning and rapid later due to high cycle loading and inspections are impractical

- Helicopter Dynamic Components – Durability and D.T. (Fatigue) plays a major consideration in the design.

Key Design Parameters -Rotorcraft

- Dynamic and Aerodynamic Requirements (Stiffness and Frequency placement)
- Static Strength
- Fatigue Strength and Fatigue Life
- Damage Tolerance Requirements
- Weight
- Producibility
- Interchangeability (very close tolerance components)

Durability vs. Damage Tolerance

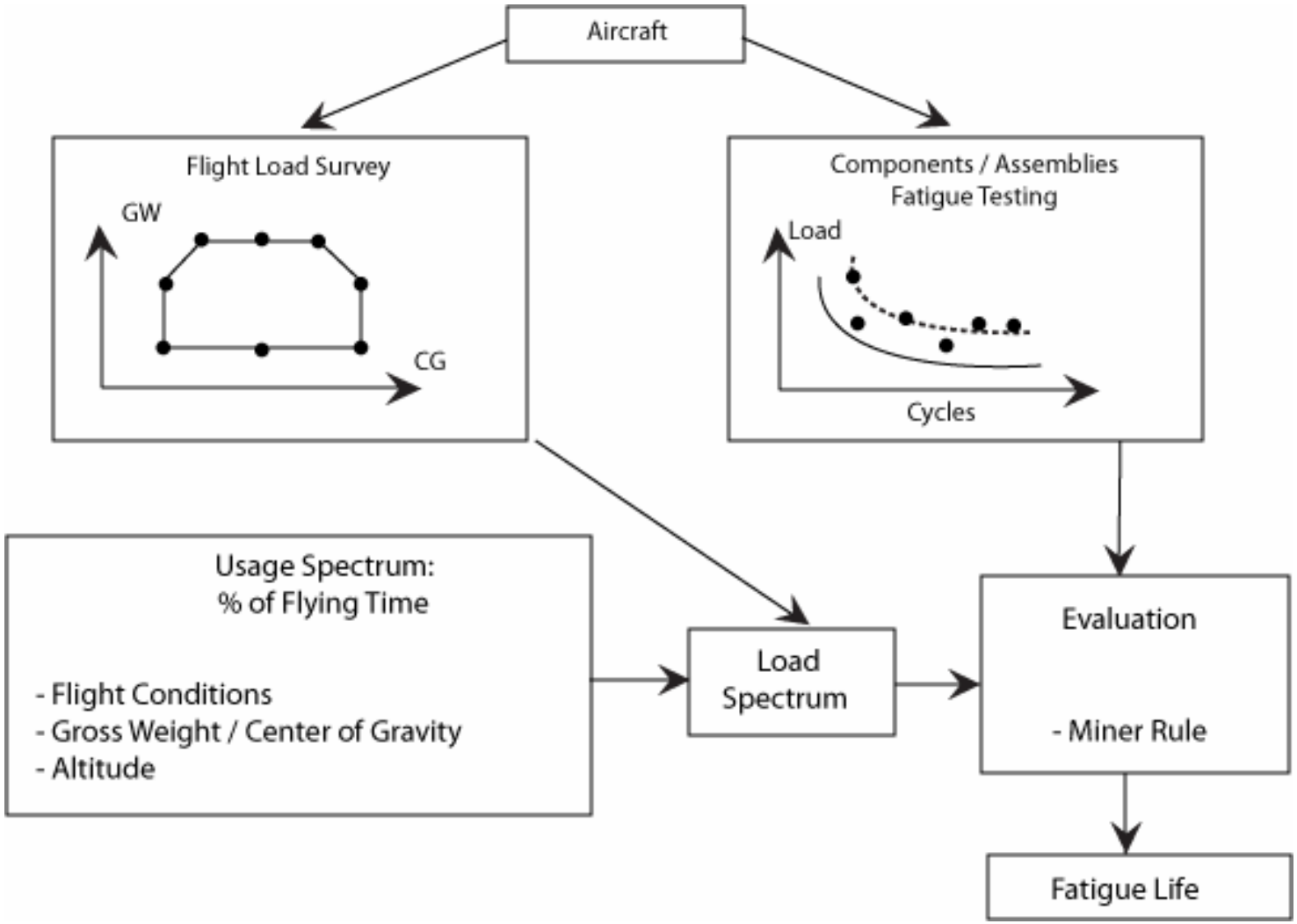
- DURABILITY
  - Characterization of crack initiation (metals) or initiation of delamination (composites) in a pristine component due to cyclic (fatigue) loading
- DAMAGE TOLERANCE
  - Characterization of growth of existing crack (metals) or delamination (composites) due to cyclic (fatigue) loading

- Most helicopters certified thru 1990 were only required to meet Durability (Safe Life)
- Recently most all helicopters and tilt-rotors have to meet Durability, as well as, Damage Tolerance requirements

Helicopter Certification Process

- Historically, helicopter components have been designed and certified using safe life approach (durability)- does not account for failures due to presence of defects.
- Since 1990's certifying agencies are also requiring damage tolerance in addition to safe life to improve safety
- Fatigue test 4-6 Full scale components of each critical assembly to define the fatigue strength curve (20 to 40 components)
- Measure flight loads/stresses in these critical parts (100 to 400 gages).
- Measure loads for 100 to 200 flight conditions, 6-12 gross weight , c.g and 3 to 4 altitudes (1800 to 9600 flight conditions)
- Determine Fatigue life using strength curve, flight loads and expected severe operational usage of the aircraft

Safe Life Methodology



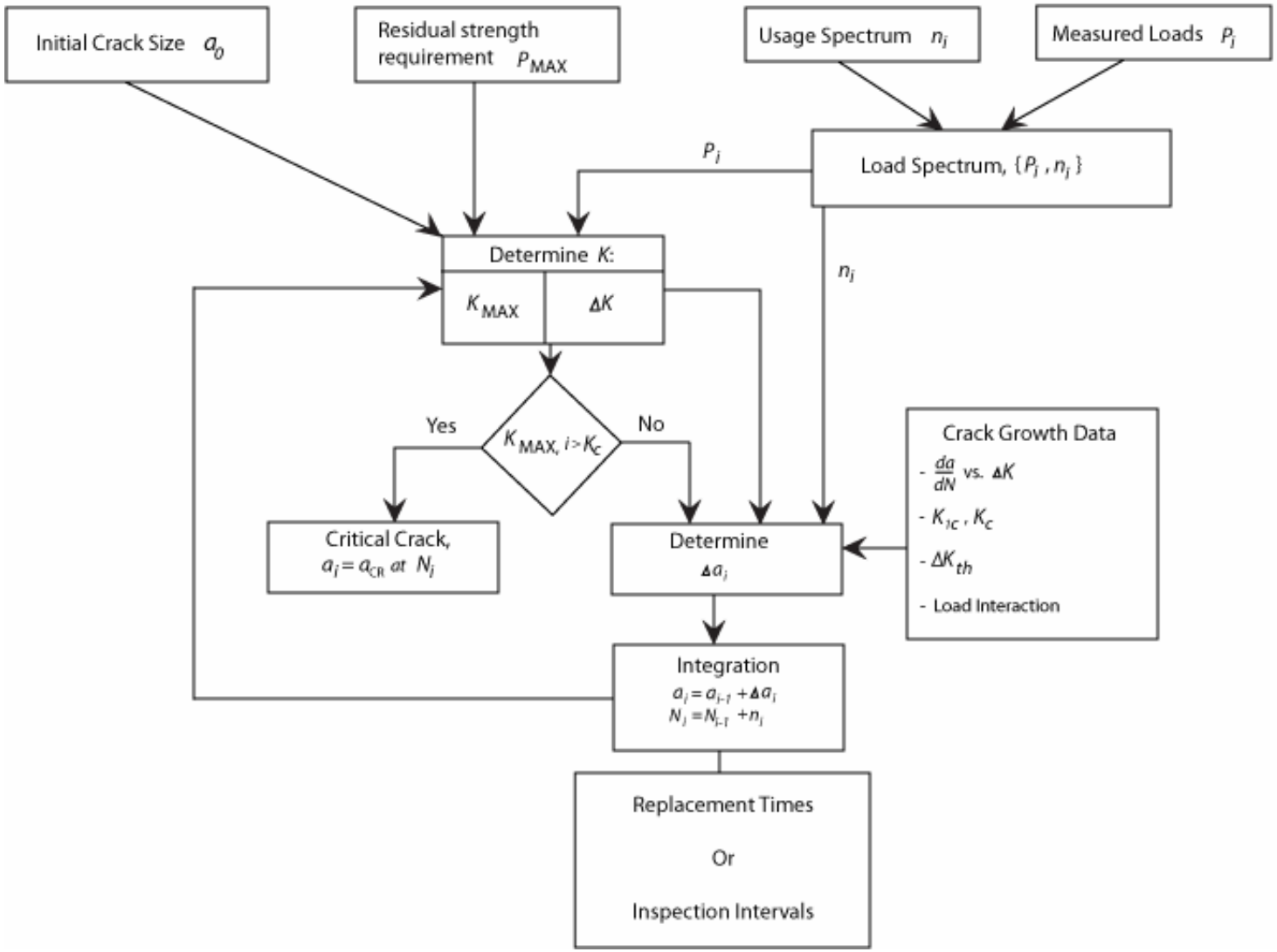
Damage Tolerance Methodology

- Assumes flaws or damage (manufacturing or service induced) present in the structure
- Demonstrate by analysis and/or tests that the component with damage does not fail catastrophically in the established replacement time or inspection interval
- Also demonstrate required residual strength at the end of components life or inspection interval
- If inspection intervals and procedures are established to detect damage, no need to establish a specific life
- Operators with less severe usage would benefit with a longer economic life without compromising safety

Damage Tolerance – Metallic Components

- Define initial crack size
  - Manufacturing experience and service history
- Define stress/load relationship
  - FEM (3D Analysis)
  - Strain gage survey
  - Spate
- Measured flight loads
- Usage Spectrum
- Residual strength requirement
- Crack growth data (da/dn vs. Delta K), crack growth threshold, Fracture toughness
- Crack growth analysis to establish inspection interval or replacement time

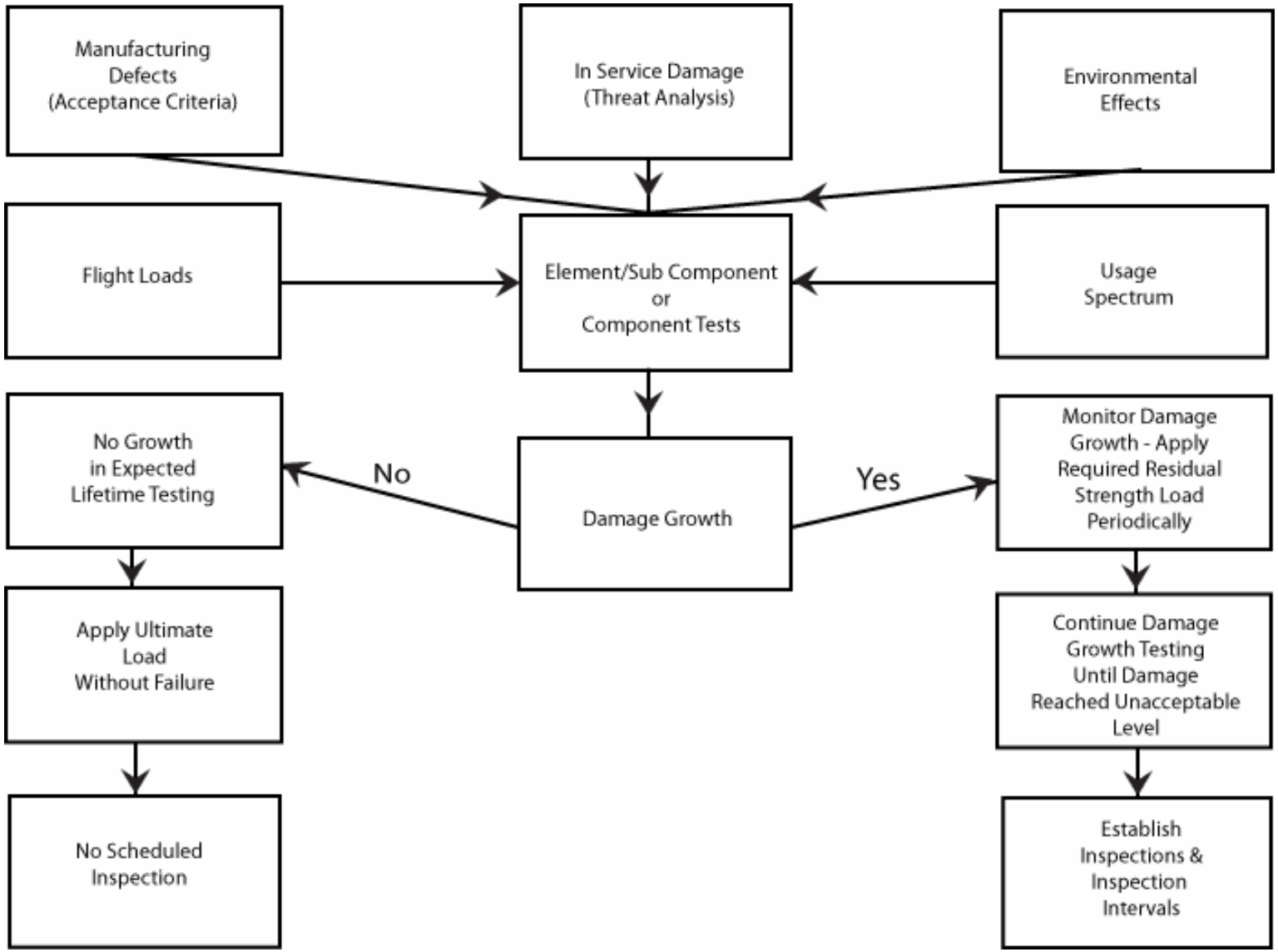
Damage Tolerance –
Metallic Components



Damage Tolerance -
Composite Components

- Manufacturing defects-Voids, Waviness etc. (acceptance criteria)
- Expected in-service damage (threat Assessment)
- Environmental effects
- Expected Loading Spectrum (including maximum load)
- Ultimate load
- Element/component repeated load tests with damage and environment simulated
- If damage does not grow during tests, perform ultimate load test at the end of required life testing
- If damage grows, monitor the damage growth till damage reaches unacceptable level (does not meet residual strength requirement)

Damage Tolerance -
Composite Components



FTI Processes and Products

Split Sleeve Cold Expansion™

ForceMate®
Bushing Installations

ForceTec®
Rivetless Nut Plates

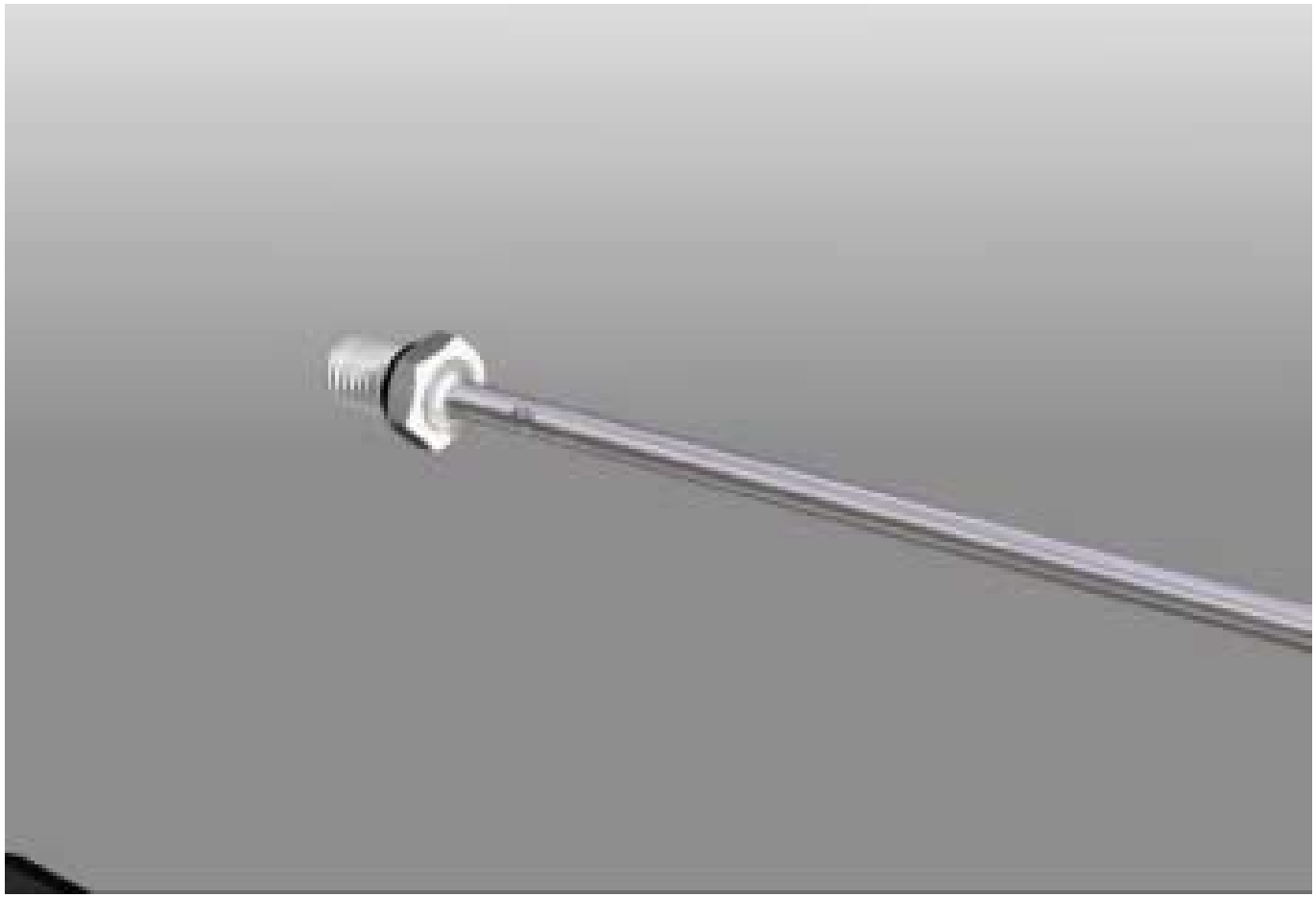
TukLoc®
Blind Fastening System

FleXmate®
Advanced Aerospace Fittings

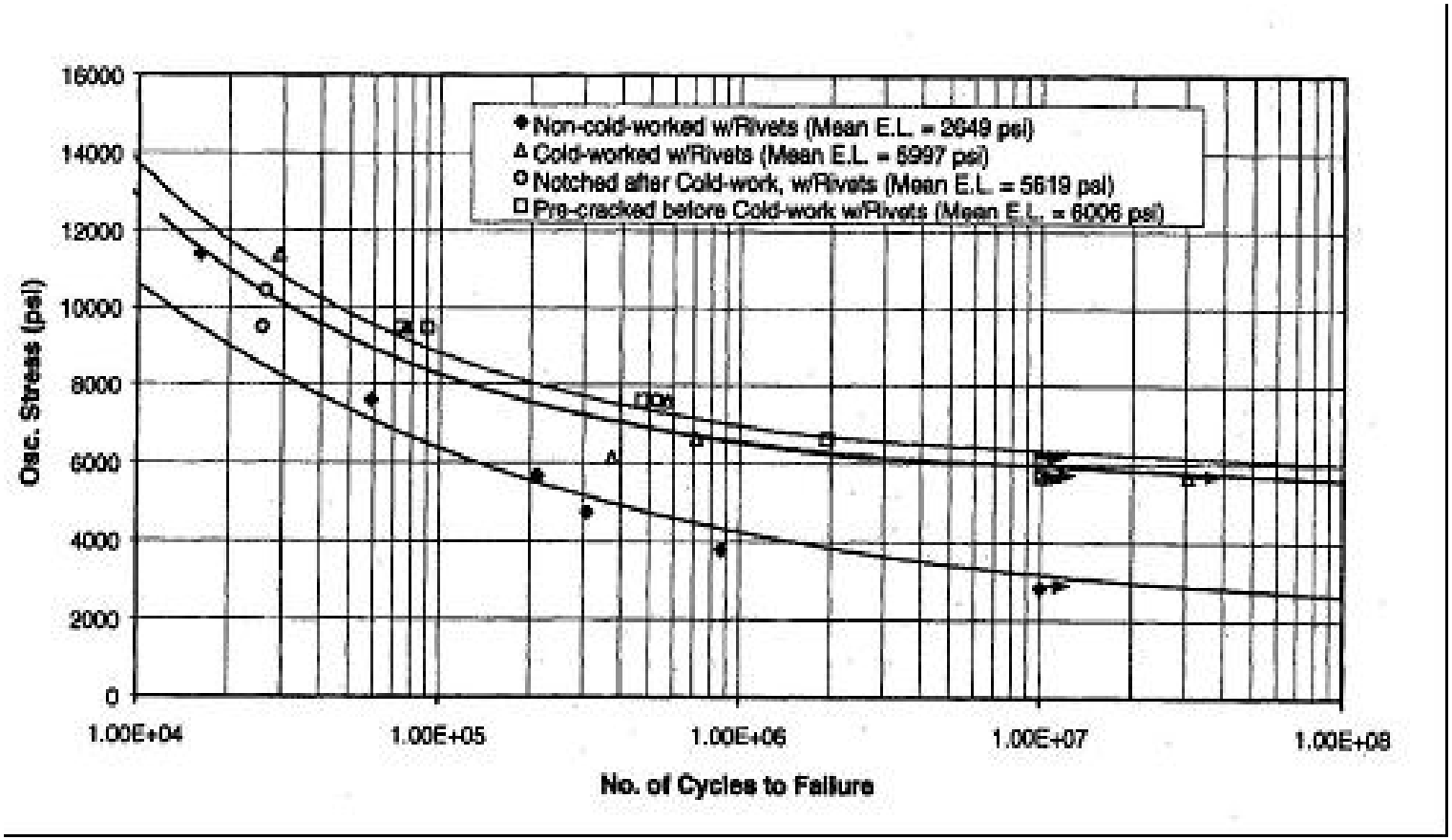
Advantages of *FTI* Processes for Fatigue Improvements

- Metallic structure is generally fatigue critical in tension loading
- Most of fatigue cracking problems occur in highly loaded fasteners holes or bolted joints
- Using *FTI* processes such as cold working and Forcemating increases joint fatigue strength significantly in the high cycle region, there by allowing to reduce the weight in the design process
- *FTI* processes help solve existing service problems, without increasing the size of the part or changing the stiffness of the system. This has significant advantage from certification perspective
- In helicopters, changing the system stiffness requires verification of the loads and dynamic behavior, which is very expensive

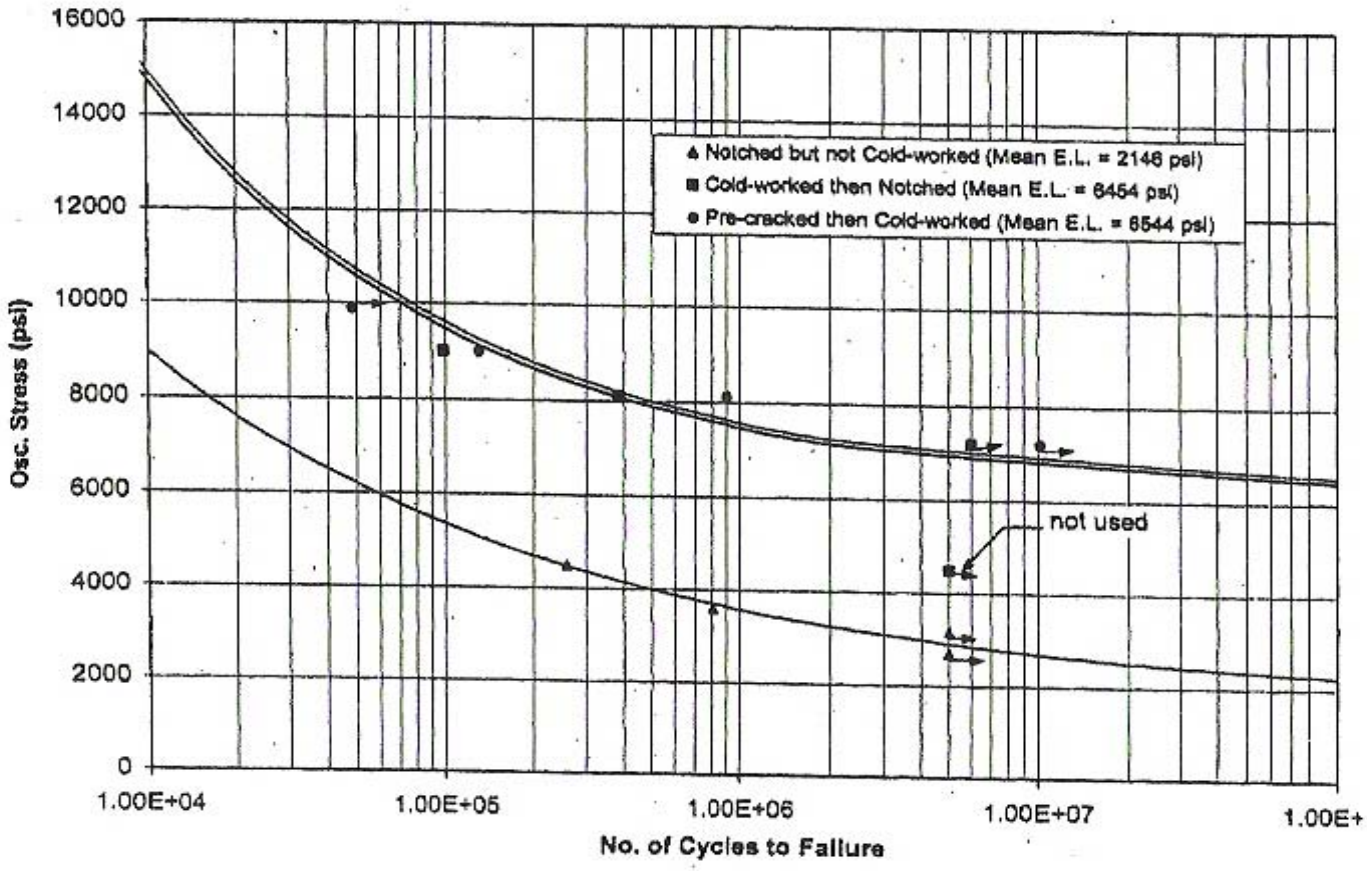
FTI's Solution-
Split Sleeve Cold Expansion



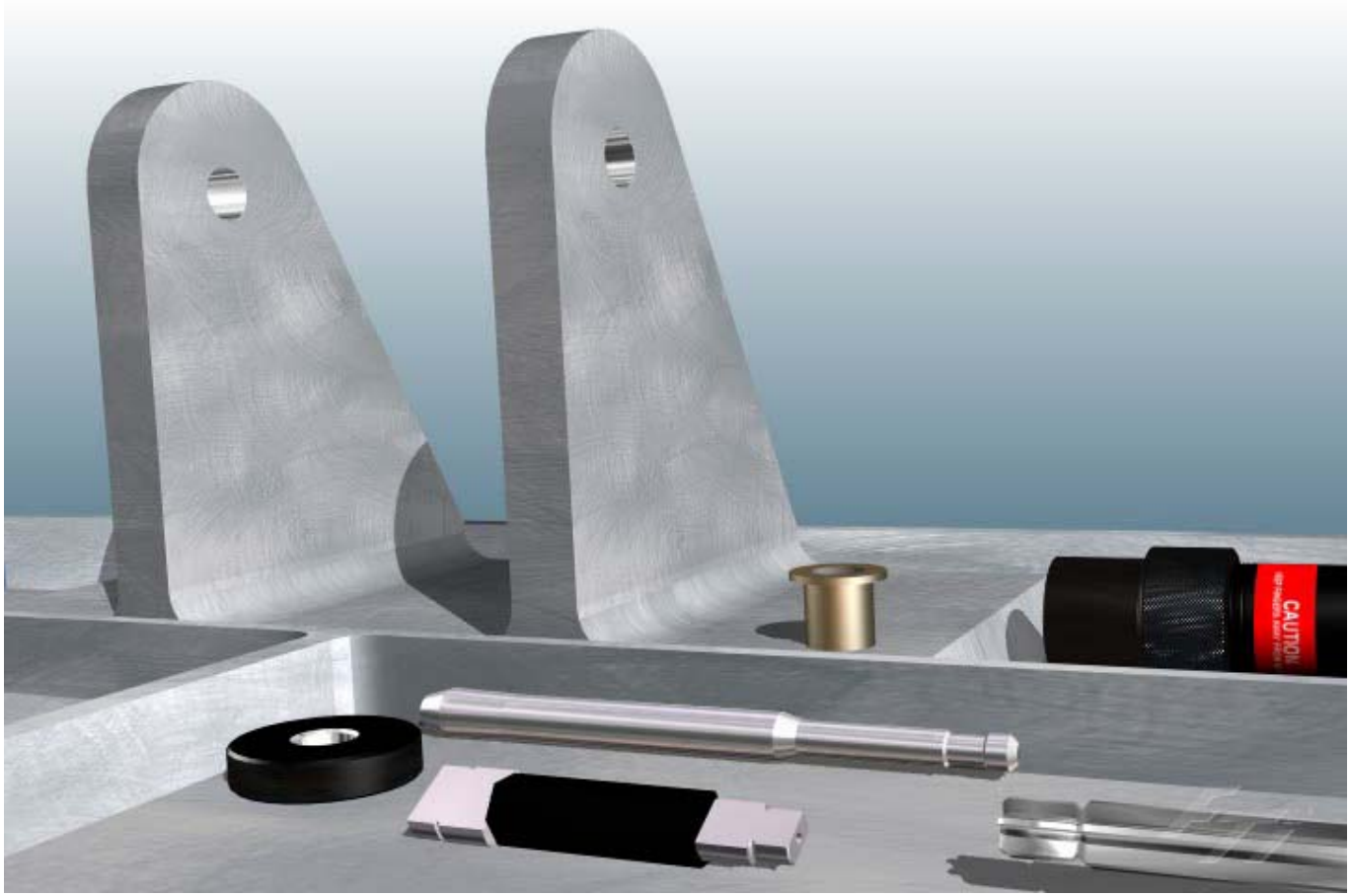
HCF S-N Curve for 2024-T3 thin Sheet Load transfer Riveted Joint R=0.05



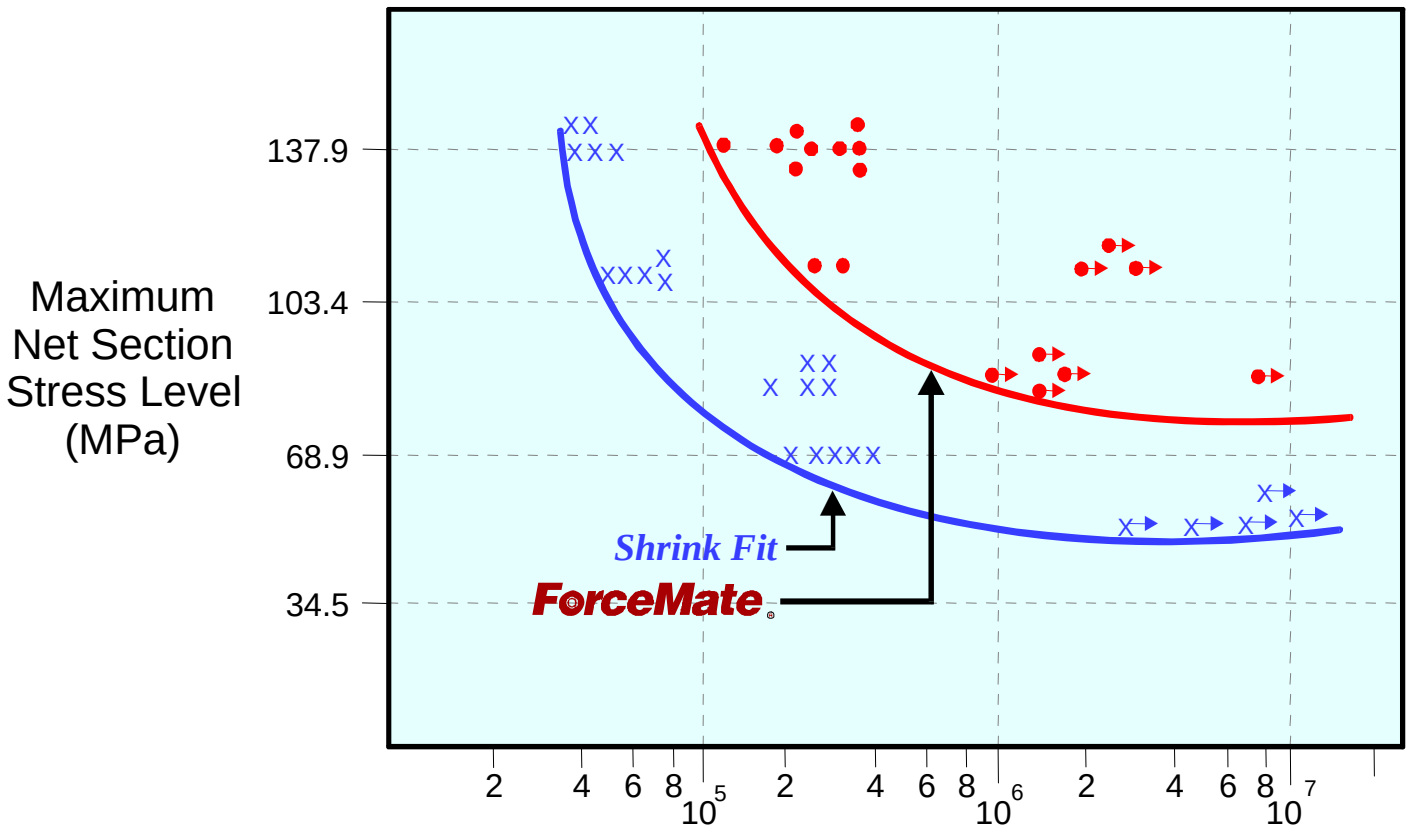
HCF S-N Curve for 2024-T3 thin Sheet Open Hole Data with and without cold working R=0.05

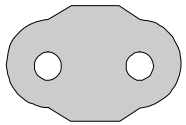


ForceMate
Bushing Installations



Fatigue Life Comparison
Shrink Fit and ForceMate Bushing Installations





Test Specimen
7075-T651

Load Conditions:
Constant amplitude
10 Hz
R = .05
Beryllium Copper Bushings

- **ForceMate Failure**
- **Shrink Fit Failure**
- **No Failure**

Champoux & Landy
ASTM STP 927
1987

Note increase in fatigue strength.

Additional Benefit from Anti-Fretting Coating

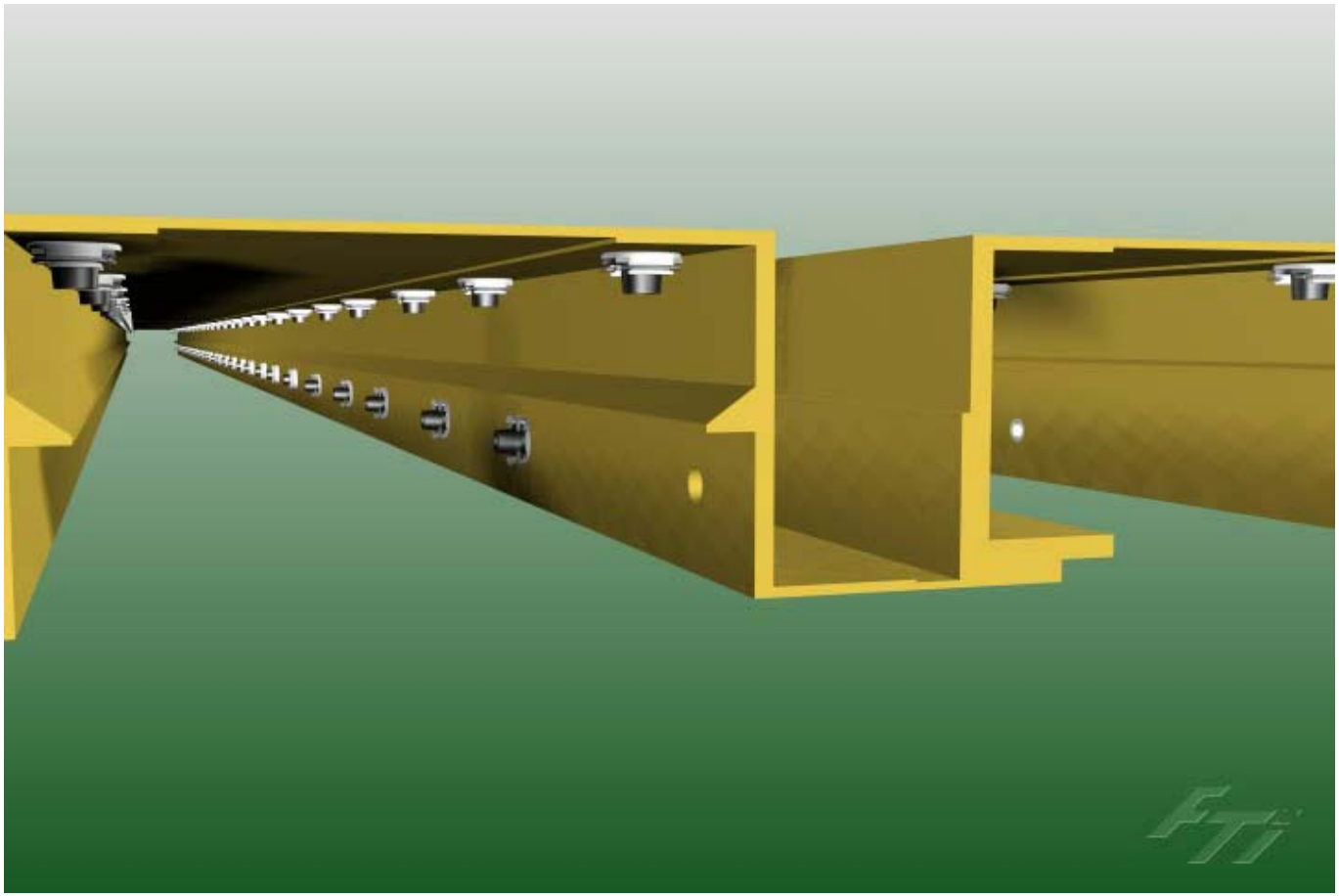
High cyclic oscillating stress causes micro-movement

- Induces fretting in hole
- Initiates fatigue crack

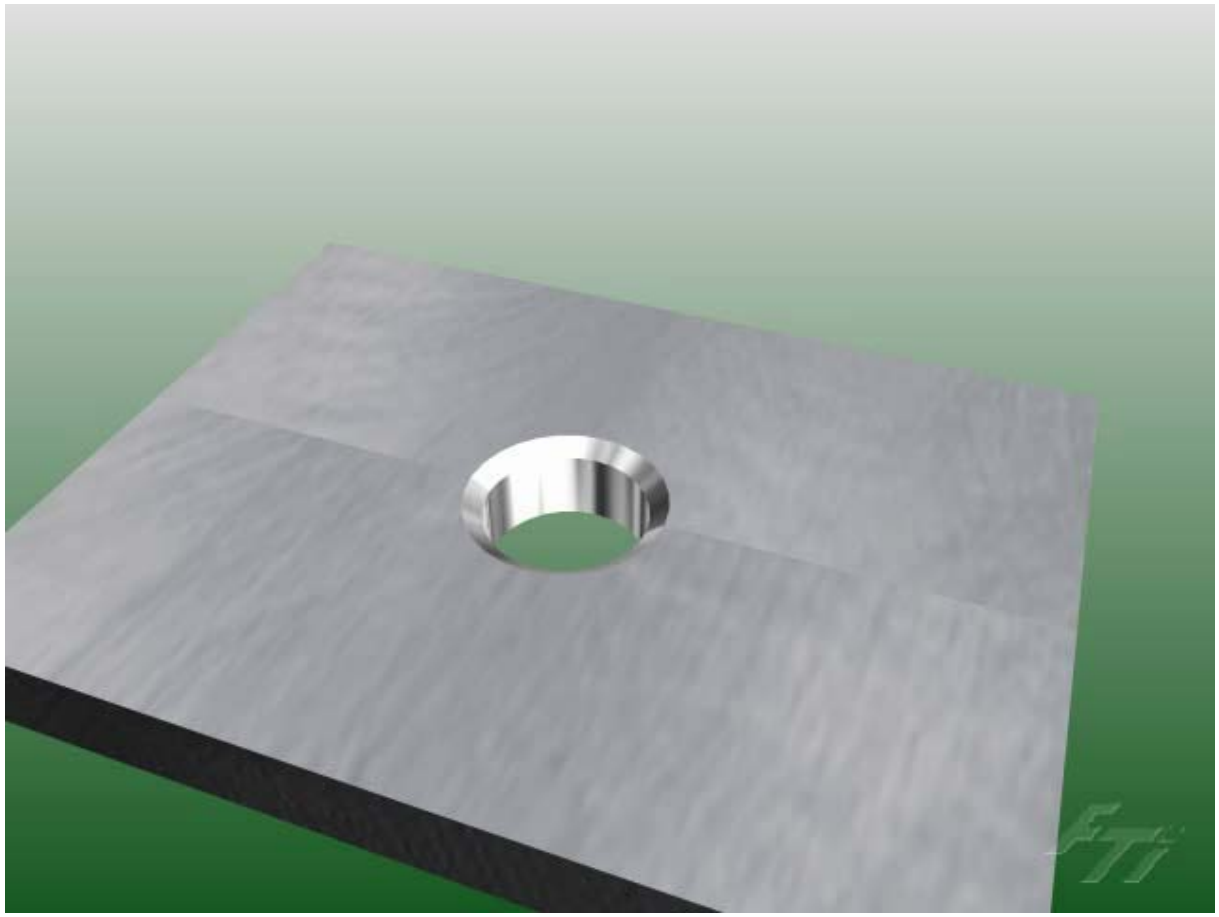
"Bluecoat" epoxy coating developed by Bell Helicopter Textron

- Shown to increase endurance of ForceMate bushing installations
- Eliminated fretting initiated fatigue cracking
- Reduced scatter of fatigue test results
- Reduced probability of galvanic corrosion
- Made bushing removal easier

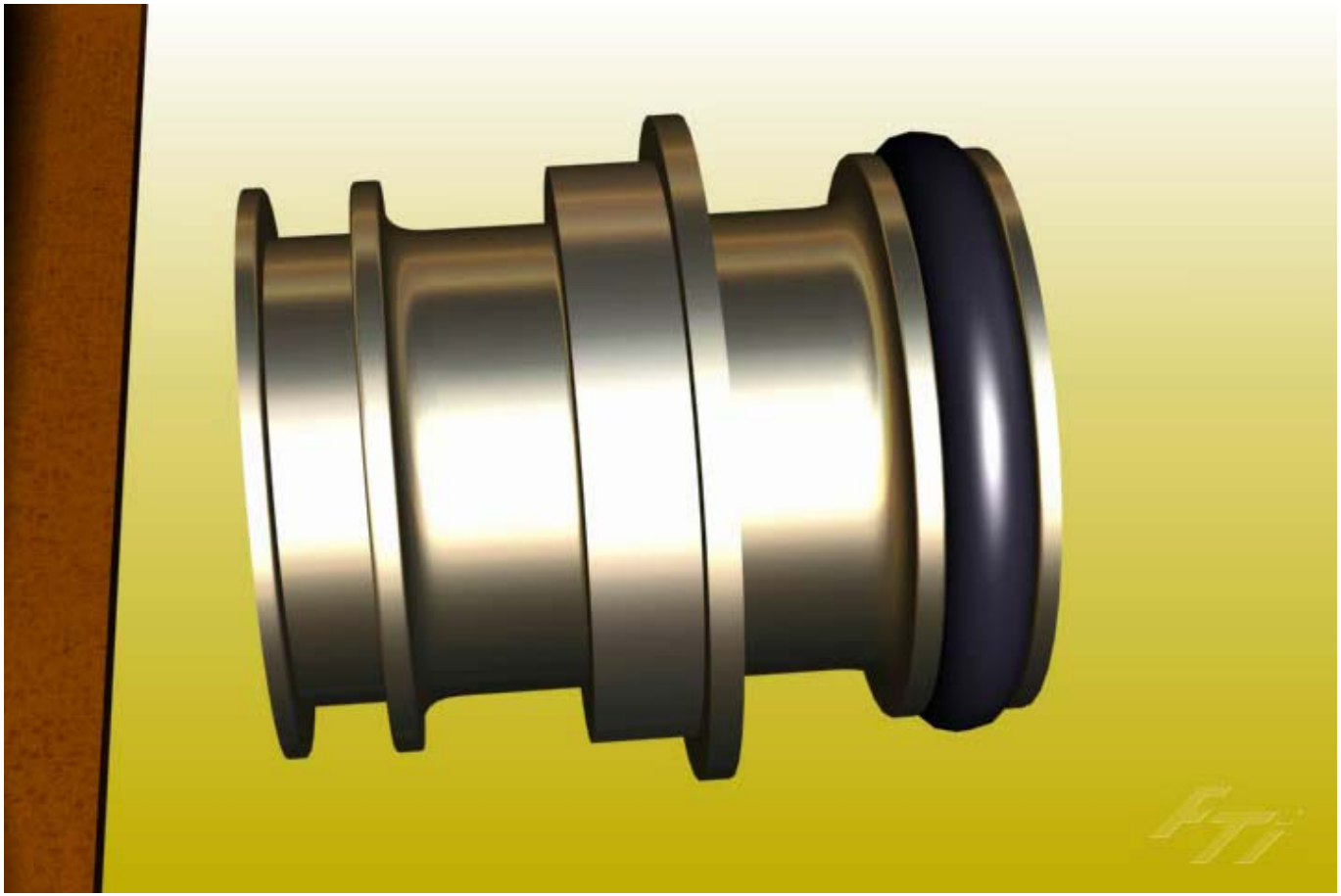
ForceTec - Rivetless Nut Plates



TukLoc -
Blind Fastening System



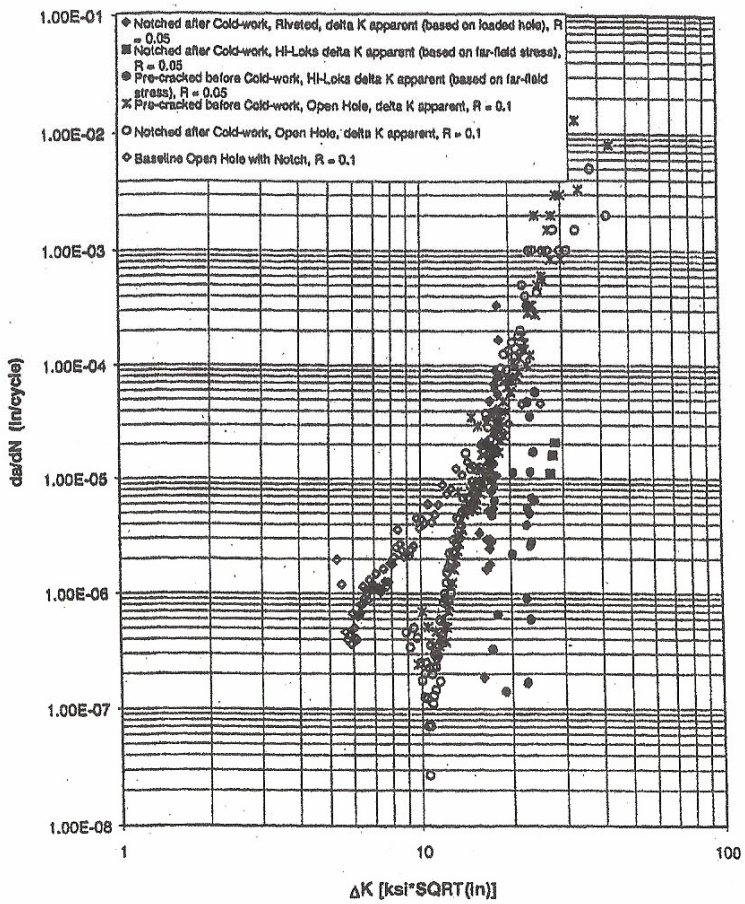
FleXmate - Advanced Aerospace Fittings



Advantages of *FTI* Processes for Damage Tolerance Improvements

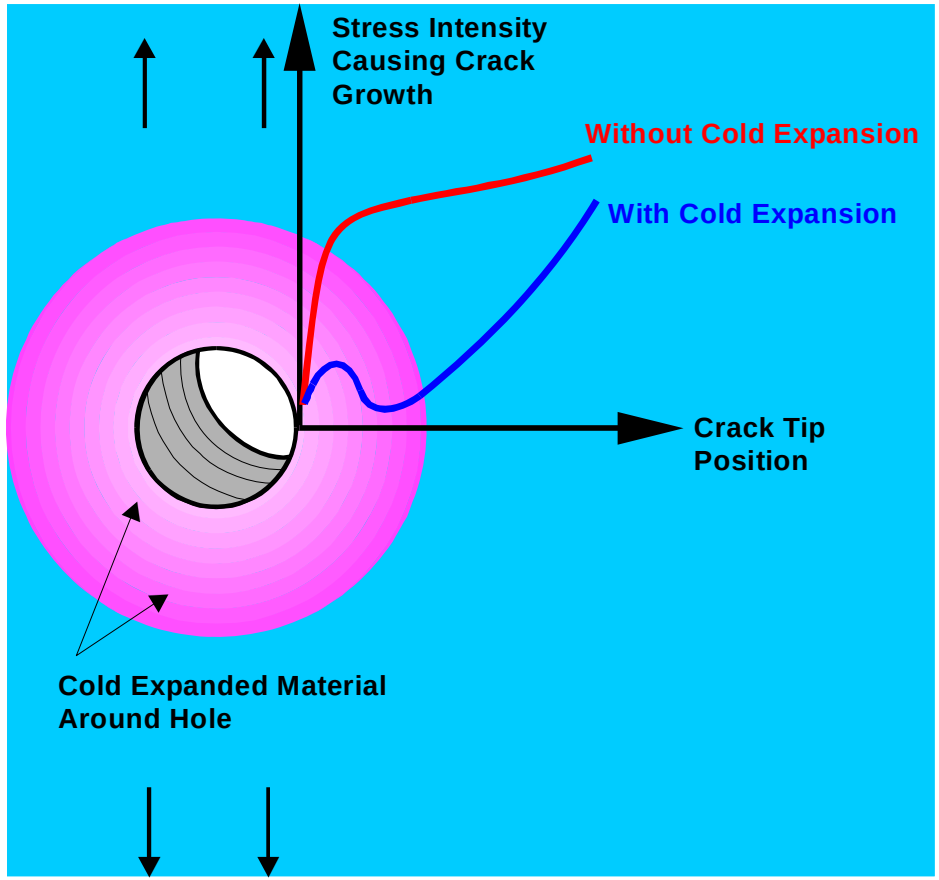
- Improve damage tolerant characteristics significantly in the slow growth and no growth regions, which is extremely important for Helicopter design
- Reduce structural weight
- Help meet damage tolerance certification requirements
- Solve service problems without elaborate design and validation process
  - Validation of design changes such as stiffness changes in the structure are very expensive

Advantages of *FTI* Processes for Damage Tolerance Improvements



ForceMate Damage Tolerance

- Combination of compressive residual stress and high interference fit reduces effective local stresses and crack growth
- Reduction in effective stress intensity (ΔK)

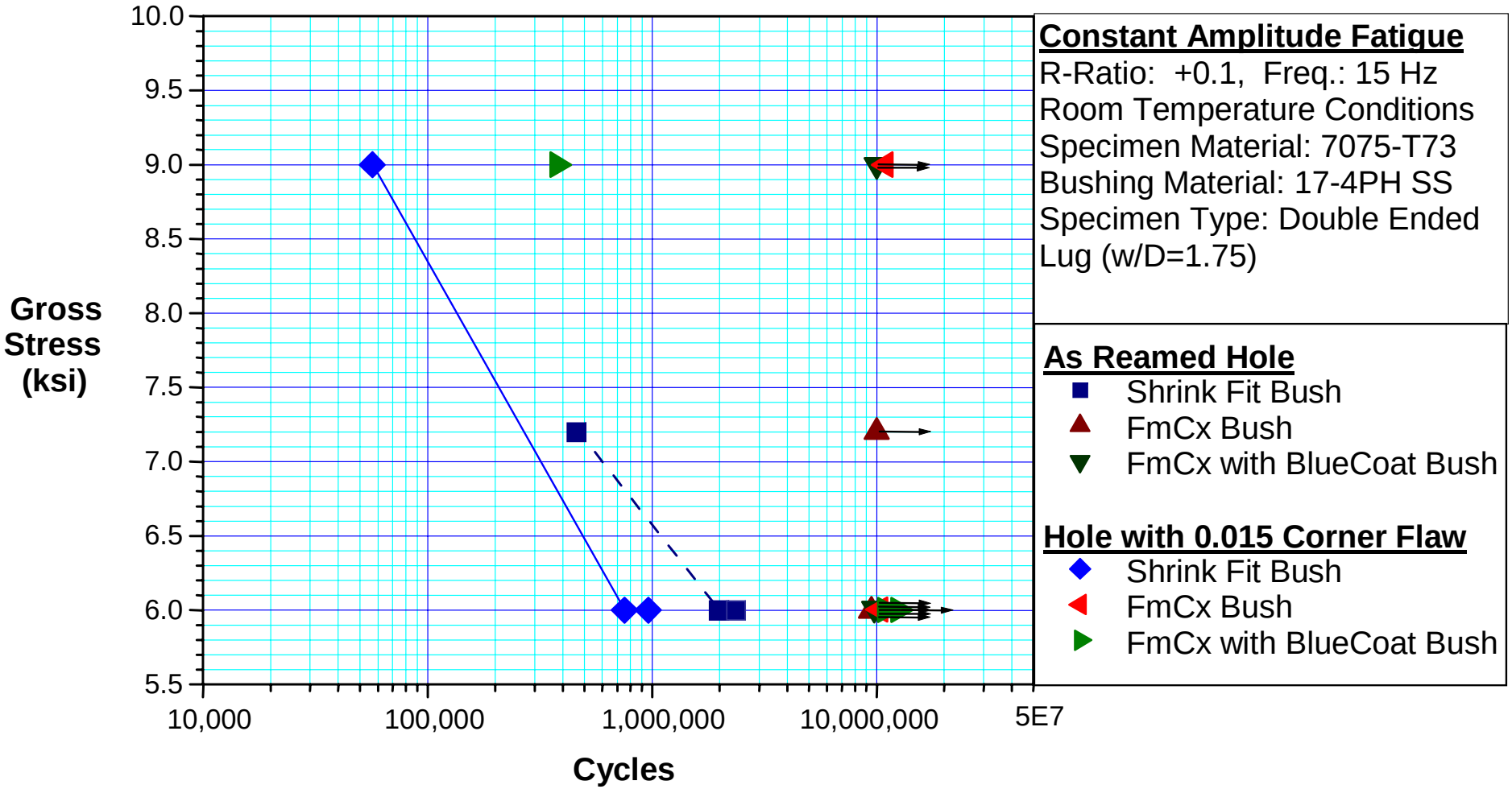


Damage Tolerance--Testing has shown ForceMate greatly increases damage tolerance of bushing installation under HCF load conditions.

ForceMate Damage Tolerance Under HCF Load Conditions

- Tested typical lug specimens under simulated helicopter HCF conditions
- Compared shrink-fit bushings to ForceMate bushing installations
- With and without 0.015 inch corner flaw in holes

Results of HCF Damage Tolerance Test

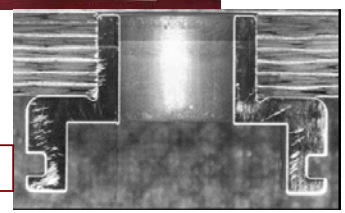


FTI- Composite Research

Expanded Hole Reinforcement in Composites

FTI is conducting research into the benefits of expanding products into a range of composite materials; benefits include:

- Retention
- Static Bypass
- Fatigue Bypass
- Static Tension Joints
- Open hole compression
- Fatigue Joints
- Lightning Strike, Conductivity

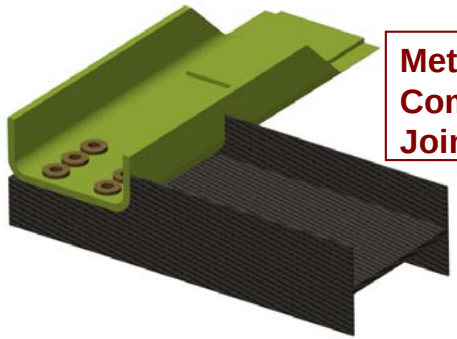


Expanded nutplate

FTI –Composites Research

Composites Program Results

- Expanded technology products offer benefits for composite design
  - Structural improvements
    - Enhanced durability of load transfer joints
    - Hole reinforcement – open hole compression improvement
    - Enhanced conductivity _ lightning strike protection
  - Manufacturing time reductions & Cost savings



Metal to Composite Joint

Expanded grommet lasted 5 times longer than conventional bonded grommets in load transfer joint

Applications of *FTI* Processes and Products in Rotorcraft Industry

- Widely used in Bell Products including V-22 and AH-1Z, UH-1Y, BA 609 and also to address service difficulties in the primary structural elements of older models
- Sykorsky S-92 and Agusta A139 designs
- *FTI* products are widely used in the commercial and military Fixed Wing Aircraft

FTI Capabilities

- Engineering R & D to develop unique solutions to unique problems
- Manufacturing and tooling capability for specially designed products
- Materials Testing facility for durability and damage tolerance testing
- Training

Summary

- Helicopter components are designed by high frequency loading
- Damage tolerance is required for future helicopter certifications
- Using ***FTI*** processes and products reduce weight and improve durability and damage tolerance characteristics significantly in the high frequency region for metallic structure
- Using ***FTI*** processes help solve service problems in metallic structure more economically
- ***FTI*** products significantly improve hole wear and open hole compression type allowables in composites
- ***FTI*** has significant presence in Helicopter Industry

FTI Contact Information

www.fatiguetech.com

(206) 246-2010

401 Andover Park East

Seattle, WA, 98188

Dean Madden, Regional Manager

972-745-6767

D.J. Reddy, *FTI* Technical Consultant

817 791 1955


Thank you.
Questions?